

DESIGNING FOR 1000-YEARS, EROSION PROTECTION

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ABSTRACT

Under requirements of the US Nuclear Regulatory Commission (NRC), Anderson was involved in the design and construction of a waste disposal facility that has a functional life similar to that of the great Egyptian Pyramids. Although this analogy seems extreme, the facility was required to have the design capacity to withstand the elements for a period of 1000 years. In the case of this uranium tailings facility, it was required to provide control release of radiological hazards for the term.

The Bluewater Uranium facility was the first non-government Title II site to be approved by the NRC for long-term custody. The accomplishment provided a model for others in the uranium industry to follow for final reclamation of uranium processing. The reclamation was a complex correlation of engineering design, regulatory compliance, environmental clean-up, and radiological health and safety.

Although many aspects of this project could be discussed including geotechnical stability, tailings impacted soils, relocation, and radiological source isolation, we focused on the engineering aspect of design and construction of erosion protection to satisfy the demands of the 1000-year term. This design included critical land shaping, runoff controls, erosion controls and overall watershed management to address the long-term stabilization of the radioactive wastes.

Approximately 3.2 million cubic yards of tailings impacted soils and evaporation pond residues were excavated, placed in repositories, and reclaimed. Around 2.0 million cubic yards of radon barrier cap material was placed and compacted over the graded features and over 1 million cubic yards of topsoil was hauled and prepared as seedbed for revegetation. Approximately 1,350 acres of former evaporation ponds and the soil borrow areas were revegetated. Approximately 500 cubic yards of rip rap and erosion protection rock was placed as well.

Erosion protective covers were constructed on the carefully shaped features that consisted of either topsoil with revegetation or rock armored. The entire repository surface was rock armored and large riprap relief spillways were designed and built for water handling and relief. All outcrops received a filter material and a larger rock size for the protective cap. The entire watershed was designed for extreme rainfall and runoff.

INTRODUCTION

Protection of public health and the environment from possible migration of hazardous materials has required the implementation of vigorous design methods. Current stabilization procedures include capping of wastes with various layers of earth and other synthetic materials to isolate wastes from erosion. Waste stabilization is a long-term concern which requires isolation of wastes in a controlled situation rather than mere implementation of a temporary solution.

The design of erosion-protection covers for various types of sites involve specific

requirements to address the waste type and potential hazards. One of the areas of specific design requirements is erosion protection for uranium mill tailings sites. The erosion protection designs prepared and implemented for the Bluewater Uranium Mill Tailings Facility Reclamation is the focus of this technical paper.

The Bluewater Facility is located in Northwest New Mexico and was a Title II site as defined by the Uranium Mill Tailings Radiation Control Act. The site was operated and reclaimed under license by the NRC. Atlantic Richfield Company (ARCO) owned Bluewater and discontinued milling operations in 1982. ARCO developed a reclamation plan that met the criteria for disposal and longevity as specified in 10 CFR Part 40, Appendix A, which was approved by the NRC in August 1990. Decommissioning of the mill and reclamation of the mill area and tailings were completed by December of 1995. ARCO received approval of its Alternate Concentration Limits (ACL) and implemented an approved Groundwater Corrective Action. The site has been successfully transferred to the United States Department of Energy for long-term care.

Erosion protection covers were designed and constructed for the tailings and are related features of the Bluewater site. These included the Main Tailings Impoundment, the Acid Tailings Facility, the Carbonate Tailings Facility, Ore Stockpile Area, and the area of the decommissioned millsite for a total of 540 acres of surface area watershed. A management plan was also prepared to control site run-on and run-off.

REGULATION REQUIREMENTS

REGULATION

Reclamation standards exist at the federal, state and local levels that require stabilization of mining wastes. The regulatory responsibility for the various types of mined material are with a large group of agencies. Regulation of Uranium Tailings is under the United States Nuclear Regulatory Commission (NRC). Criteria for minimizing dispersion of radioactive Uranium Tailings, with emphasis placed on isolation of tailings and protection against natural phenomena, are established in 40 CFR Part 192 and 10 CFR Part 40, Appendix A. Specifically, 40 CFR 192.02 and 10 CFR Part 40, Appendix A, Criterion 6, require that control methods be designed to limit radioactive tailings releases to specified levels.

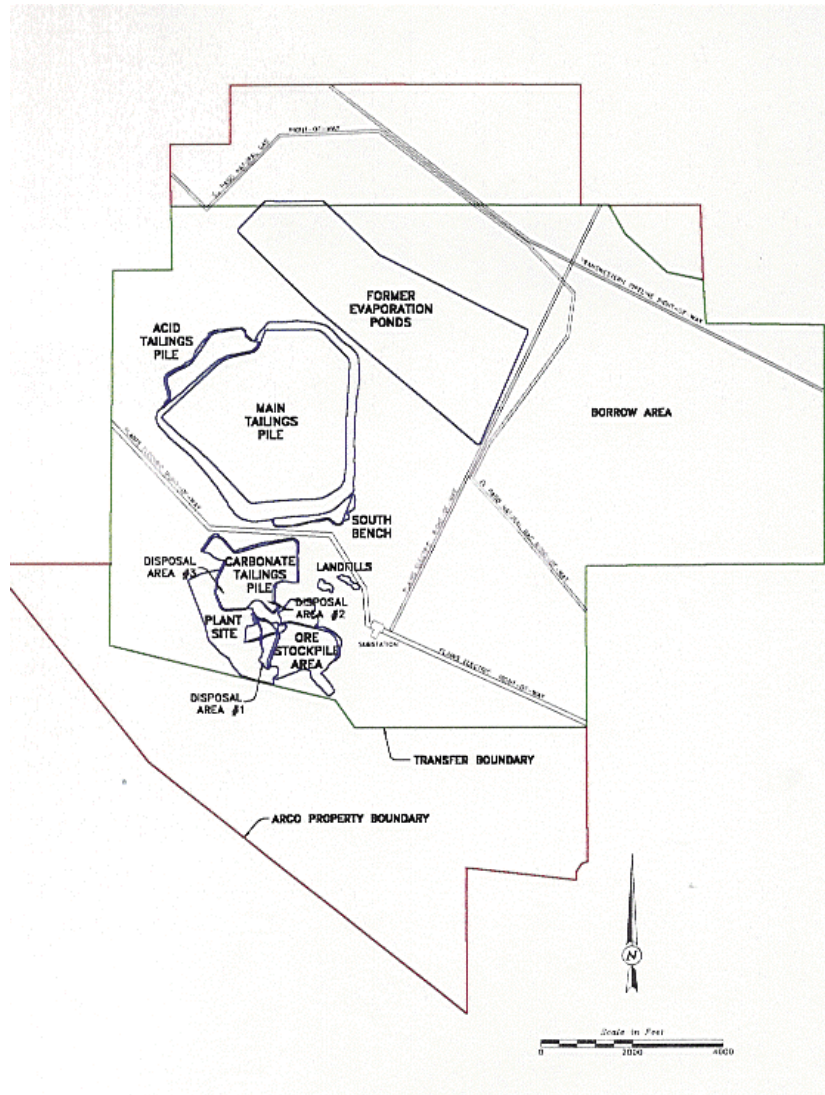


Figure 1 - Location of Tailings Facilities

LONG-TERM STABILIZATION

Several major design objectives for long-term stabilization of uranium mill tailings are established in 40 CFR Part 192 for Title I [government] sites and in 10 CFR Part 40, Appendix A, for Title II [private] sites. These can be summarized as follows: (1) prevent radioactive releases caused by wind and water erosion; (2) provide long-term stability; (3) require minimal maintenance to assure

performance; and (4) provide sufficient protection to limit radioactive releases. It is therefore critical to assess the forces associated with surface erosion, to design flood protection measures for appropriately severe flood conditions, and to minimize the potential for erosion and release of radioactive materials.

In order to control releases of Radon 222 from uranium tailings earthen covers are placed over the tailings materials. These covers range in depth dependent on the concentration of the source and cover type. The earthen caps are to be protected from erosional processes to maintain the cap integrity over time.

It is required by 40 CFR 192.02 and 10 CFR Part 40, Appendix A, Criterion 6, stabilization designs must provide reasonable assurance of control of radiological hazards for a 1000-year period, to the extent practicable, but in any case, for a minimum 200-year period. The NRC has concluded that the risks from tailings could be accommodated by a design standard that requires that there be reasonable assurance that the tailings remain stable for a period of 1000 (or at least 200) years. Erosion protection is to be passive control such as earth and rock covers rather than ongoing routine maintenance.

Regulations state that tailings should be disposed of in a manner such that no active maintenance is required to preserve conditions of the site. Criterion 12 states that: **A**The final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation.**@** The NRC has defined active maintenance as any work that is needed to assure that the design will meet specified longevity periods. Such maintenance includes even minor maintenance, such as the addition of soil to small rills and gullies. The question that must be answered is whether longevity is dependent on the maintenance. If it is necessary to repair gullies, for example, to prevent their growth and ultimate erosion into tailings, then that maintenance is considered to be active maintenance.

DESIGN ALTERNATIVES

For design of erosion protection covers there are many options and design combinations that can be implemented. The design is to consider site specific conditions and erosional potential. Erosion protection designs generally fall into several categories. Taking into account the experience with erosion and reclamation design from mining and reclamation completed in the southwest United States the following are the design alternatives used for long-term stabilization:

- \$ Soil covers designed to be stable for 1000 years.
- \$ Combinations of soil covers on the top slopes and rock-protected soil covers on the side slopes, both designed to be stable for 1000 years.
- \$ Soil covers totally protected by a layer of rock riprap on both the top and side slopes.
- \$ Sacrificial soil covers designed to permit controlled erosion.

A combination of these design alternatives were utilized at the Bluewater Uranium Millsite. The size, geometry, layout and watershed impacts were evaluated for each millsite feature to be stabilized. Figure 1 shows the site layout and relative sizes of the features to be stabilized. A total of 540 areas were to be stabilized for long-term erosion. Approximately 320 acres of the evaporation ponds were removed and consolidated into the Main Tailings facility.

DESIGN STORM EVENTS

PRECIPITATION

The design precipitation event and resulting flood is that which would statistically not occur more than once in 1000 years. Such statistical analysis to estimate a 0.001 storm probability is not reliable. Therefore, the design approach used for the Bluewater project was based on site extreme meteorological and hydrological characteristics. The probable maximum precipitation (PMP) and the probable maximum flood (PMF) are events of very low likelihood to occur. NRC accepts the use of the PMP and PMF design events for erosion stabilization design. The PMF has been defined (COE, 1975) as the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The precipitation associated with the PMF is known as the PMP which is defined as the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage basin at a particular time of year (AMS, 1959).

Analyses were performed utilizing a PMF based on the ratios between the 6-hour general storm and the 1-hour local storm PMF. (Hydrometeorological Report -HMR No. 55A). Maximum depths were adjusted by the 6/1 hour ratio recommended for the Bluewater area. (HMR No. 49). The estimated 6-hour depth for the local storm PMP is 13.47 inches. PMF discharges were computed by use of the computer program Army Corp of Engineers HEC1 model. Anticipated surface flows were evaluated by use of HEC2, calculations and computer programs designed for natural channel evaluation.

WIND EROSION

Prevailing winds at the site originate from the west and southwest of the Bluewater Site. These winds will have a direct impact on portions of the tailings embankments and on the top surface of the Reclaimed Tailings Facility. An estimate of wind erosion potential was made using the Wind Erosion Equation (Israelsen et. al., 1980).

Estimated losses using this methodology for reclaimed embankments at 5 horizontal to 1 vertical slope configuration for the tailings pond indicate the need for a rock-type, wind-erosion protection. Such slopes will receive rock-cover protection. Estimated wind erosion on the re-contoured tailings top surface for the same design period indicated some soil loss. Rock protection designed for water erosion would adequately protect against wind erosion. Minimal losses are projected for the adjacent reclaimed facilities surrounding the Main Tailings pond.

LAND SHAPING

The top surfaces and slopes of the various waste impoundments were shaped to comply with regulations and also to meet design objectives for erosion control. All out-slopes of the Main Tailings

Impoundment, Acid Tailings, and Carbonate Tailings were graded and shaped to a 5 to 1 geometry. This slope geometry is permitted in regulations when protected by rock covers.

Impoundments and other reclamation area top surfaces were graded to promote runoff from the feature surface. The land shaping also allows for flatter areas to be stabilized to meet the 1000 year requirement with soil covers and vegetation. The slopes on top surfaces must allow for drainage to eliminate standing water that can pose unwanted infiltration into the tailings and also not be excessively steep so as to cause water erosion from erosive flow velocities.

The final design surface grade of the Main Tailings was 3.8% over 252 acres and 2.8% over approximately 50 acres of the top surface. This slope shaping allowed for feasible volumes of cut and fill placement and also standing water on the surface.

The maximum slope length for the sand tailings area is 2250 feet. The maximum slope in the sands was used for the erosion protection calculations to maintain a safe, conservative design. Approximately mid-way across the impoundment, the grade becomes less than 0.5% and continues at this grade for an average of 2600 feet to the northern edge of the impoundment.

The maximum slope grade and slope length for the Carbonate Tailings are 3.0% and 1350 feet respectively. The surface of the Main Tailings and Carbonate Tailings required the placement of erosion-protection rock cover over the cap for long-term stabilization.

The Acid Tailings and South Tailings areas were graded to a stable slope design on the top surface. With the configuration of the surface less than 0.5%, soil covers were utilized with revegetation over these areas.

WATERSHED MANAGEMENT

The management of run-on from the upstream watershed was a critical design consideration for erosion stabilization of the impoundments at Bluewater. For the design of erosion protection, two different situations related to the watershed drainage must be considered. For an impoundment located in the flood plain of a major stream or wash, the PMF of concern would be that caused by an occurrence of the PMP over appropriate drainage areas upstream of the impoundment. The impact on the toe or face of the impoundment depends on the magnitude of the PMF and the location of the impoundment relative to the main drainage. Some sites are located on high ground beyond the influence of the PMF of a major drainage. For these cases, the PMF of concern is that corresponding to occurrence of the PMP on only the drainage area on and above the impoundment site.

A PMF occurring on the up-gradient watershed could influence surface erosion of the impoundment. These flows should be diverted around the reclaimed impoundment with diversion structures designed to withstand the calculated up-gradient PMF and any influence from the onsite PMF.

The upstream watershed drainage for the Bluewater Tailings Impoundment was estimated to be substantial for the PMF (7000 cfs). The stabilization of the 320 acre evaporation pond network within the watershed drainage path was extreme. To meet long-term stabilization needs and also to the extreme cost of rock cover the evaporation ponds were consolidated into the Main Tailings facility. The flow pattern of the upstream watershed could then be diverted away from the tailings impoundments and only the onsite precipitation considered for the out-slope erosion protection design. A 6300-ft long open channel was designed and constructed up watershed to divert flow

through the drainage area and direct flows downstream of the reclaimed facilities.

SOIL/VEGETATED EROSION PROTECTION COVER

Soil cover for erosion protection of the impoundment caps are only acceptable for flatter-top slopes. Soil covers are not recommended for side-slopes as the vegetation may not be able to resist gullies originating on the steep side-slopes. Vegetated soil covers also may have sufficient resistance to prevent advancing head-cutting from natural drainages surrounding the impoundment. The use of soil covers with vegetation must be shown to contain a self-sustaining plant community that will be sufficiently dense to reduce erosion potential. Soil covers alone likely will not be capable of providing long-term stability on slopes steeper than 1-2%. Soil covers with vegetation can be implemented when designed to be stable. Design is to account for precipitation conditions and stresses resulting from flow velocities of PMF events. If the shear stresses and flow velocities produced by concentrated runoff from design-basis flood events are less than the allowable stresses and velocities of the soils this cover method is acceptable to the NRC. These stresses are relative to the slope angle of the soil surface.

In addition to having a slope that is shown by analysis to be stable, the soil cover should be designed to be thick enough so that there is reasonable assurance that tailings will not be exposed and that radiological criteria will be met considering the combined effects of wind erosion, sheet erosion, and minor rill and gully erosion.

The existing slopes for the Acid and South Tailings Areas were very near flat on the top surface. The design of these areas were to comply with the following: (1) minimize the potential for development and growth of a gully over a long period of time, assuming that flow concentrations occur; and (2) prevent the erosion of tailings due to gullying.

The stability of soil-covered surfaces was determined by use of the Horton (NRC) method and the Permissible Velocity Method. The Horton method provides a direct solution of the value of the stable slope needed to prevent gully formation. Impacts for the determination included critical distance, runoff intensity, roughness factor, soil resistance, allowable shear and slope function. Permissible velocity determinations are evaluated from slope length, concentration factors, roughness, rainfall intensity, and stable slope impacts. The values are compared to published permissible velocities. The stable slopes for Bluewater were designed to be graded at 0.15 %. The calculated maximum velocity for the soil types placed was 1.05 fps which was less than the 1.5 fps acceptable maximum permissible velocity. The top slopes of these impoundments were constructed to the design specifications.

A vegetated cover consists of plants and soil, that have been selected to maximize transpiration and resistance to erosion. The soil and plants in a vegetated cover have specific performance objectives that must be met if the cover is to achieve its intended goal of controlling water, resisting erosion, and otherwise contributing to the long-term integrity of the stabilized pile. Soil types that have higher permissible velocities as defined in research are the types that should be used for cover if available.

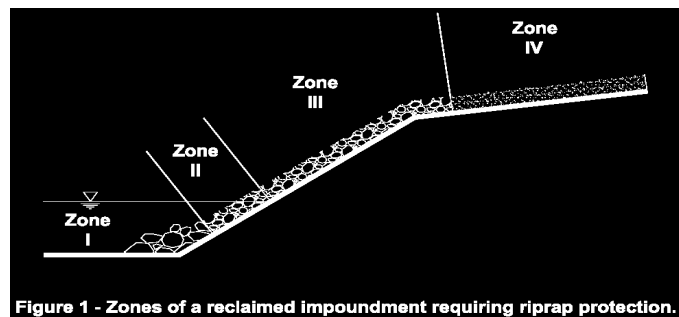
ROCK COVER

The design of stable covers and impoundment embankments requires that the surface be constructed on scour resisting material and be protected with some type of armor coating. When designing for long term periods, naturally occurring materials have well documented historic evidence of survival without significant degradation.

Several erosion protection types and methods of installation were compared while developing the Bluewater Reclamation Plan. With protection of the reclaimed features as the paramount consideration, cost of rock development and installation were also analyzed to find the most cost-effective best solution. At the time of the Bluewater Plan development, several agencies and groups had completed research on erosion protection methods for channels, however, there was limited research completed on surface protection methods where hydraulic properties are more akin to turbulent sheet flow. Despite the best intentions of the reclamation designer, over time this sheet flow action may create rills and localized settlement which can completely change the original design assumptions. To account for these long term varying conditions, covers design must incorporate significant factors of safety. No one method works for the various conditions encountered in designing cap protection systems.

ROCK DESIGN METHODS

Figure 2 illustrates the four design zones for a reclaimed cover. As described in the Long Term Stabilization design guide (Nelson, 1986).



- Zone I: Zone I is at the base of the impoundment slope and represents the area of greatest flow and hydraulic action. The riprap protecting the slope toe must be sized to stabilize the slope toe due to flood and dissipate the energy as flow transitions from the impoundment slope to the natural terrain. Zone I is considered a zone of frequent saturation.
- Zone II: This is the area along the side slope which remains in the major watershed flood plain. The rock protection must resist not only the flow down the impoundment slope, it must also resist movement from flows normal to the impoundment slope.

- Zone III: Riprap in this zone should be designed to protect the relatively steep slopes of the embankment. Zone III is considered a zone of seldom saturation.
- Zone IV: Rock protection in this area is designed for the mild slopes typical of the surface cover. Zone IV is usually characterized by sheet flow with shallow flow depths and low velocities. Zone IV is considered a zone of seldom saturation.

At Bluewater, rock sizes were designed for each zone. For purposes of constructability, in many cases the larger rock required was used for the entire slope. When using larger rock than required for momentum resistance, proper sizing of the filter is critically important to prevent erosion below the larger rock. Saturation applies primarily to the durability of the rock.

The Bluewater design team used various methods in the process of design development. Design method used for the Bluewater project used for sizing rock for long term were:

Corp of Engineers Method

The Corp of Engineers Method (BOR, 1984) was well suited for surface cover areas at Bluewater. Using equations to model the boundary shear created by the water movement to the shear the weight of the rock is capable of withstanding a d_{50} rock size is determined.

Stephenson Method

The Stephenson Method was found to be the best model for sizing rock on impoundment side slopes (Stephenson, 1979). The size of rock derived from this method is determined by input of the maximum flow velocity per unit width, the rockfill porosity, the acceleration of gravity, the relative density of the rock, the slope angle, the angle of friction and an empirical constant factor. The rock size derived is the d_{50} rock size at which rock movement is resisted for the given unit discharge.

United States Bureau of Reclamation

The USBOR method (BOR, 1984) was developed for high energy dissipation and protection of steep slopes. The characteristics corresponded with the protection requirements of the spillway section of Bluewater's Main Tailings Impoundment. The USBOR model estimates the d_{100} rock size as a function of the channel velocity.

SOIL/ROCK MATRIX DESIGN

Radon barrier and cap materials are commonly constructed from clays and silts for a number of reasons pertinent to the functionality of the design. These soil types are also fairly resistant to scour, especially when covered with grasses or other non-deep root species of vegetation. Combining the cohesive properties of the soil, the interlocking action of the root zone with the armor protection of rock in theory provides a very stable surface. Especially suited for surfaces with slopes of less than

1%, this surface also has the advantage of drawing water from the system to help reduce percolation through the waste body.

Design Process

The soil/rock matrix is practical for shallow slopes (typically less than 1%) that do not require large diameter rock. Rock is designed using standard equations as described above and graded in accordance with accepted methods (COE, 1970). The soil/rock design can typically be formulated in such a way that a filter is not required as a separate layer. The matrix depth should be a minimum of 6-inches and normally not exceed 12-inches. The maximum practical d_{50} rock size is half the depth of the matrix.

Implementation

The soil/rock matrix design was included in the original Reclamation Plan for the Bluewater Project. However, construction problems associated with homogeneous mixing of the soil and rock in the field resulted in the design team revising the design to a rock only cover on most of the project. Premixing, though higher in cost, provides a much more consistent product than field mixing.

Types of Cover - Rock

Rock only covers are well suited for the varying conditions associated with the reclamation of impoundment covers. At Bluewater, situated in the Mt. Taylor Malpais flow, good durable stone was economically available. Using the design methods discussed above, rock was designed for the varying slope conditions.

Design Process

Rock/filter covers are practical for impoundment surfaces and side slopes. Rock sizing should be designed using methods described above and graded in accordance with acceptable procedures. Filters should be a minimum of 6-inches deep. A design depth of 1.5 times the D_{100} provides sufficient depth to facilitate placement.

The rock size calculated for hydraulic conditions at the Main Impoundment was a d_{50} of 2-inch. The size of the 350 area surface and the heterogenous composition of the tailings themselves made potential differential settlement or other future uncertainties a major concern for the long term stability of the radon barrier cap. Therefore a safety factor of 3 was used on the top surfaces for areas of mild slope and a factor of 4 was used on steeper slope areas. Gradations with a d_{50} rock size of 1-1/2-inches and 2-inches were used on the tops surface areas.

The side slopes of the Bluewater impoundments were constructed of engineered fill with significantly less chance of differential settlement. This fact associated with the less critical nature of the cover allowed the design team to use a much small factor of safety. The calculated d_{50} rock size on the Main Impoundment was 2-inches. The final design specified a d_{50} rock size of 2-1/2-inches.



Rock placement on asbestos disposal area

Implementation

Rock was produced at a near site quarry with an inpit crusher and screening plant. Rock was hauled to the site and placed using bottom dump tractor trailers. Rock was then spread using graders with laser guided blades to control depth.

Types of Cover - Spillway Rock

The Main Tailings Impoundment was designed to discharge all surface water off of the north embankment which was referred to in the reclamation plan as the spillway. The approximately 1600-ft. long spillway required a larger rock to both protect the underlying surface and disipate the hydraulic energy before the transition into the natural terrain.

Design Process

The potential high energy conditions of the spillway are similar to conditions for which the USBOR method was developed. Using this method a d_{50} rock size of 4.3-inches was calculated. A 5-inch d_{50} rock was used on the spillway embankment.

Implementation

The larger rock size could not be placed using the same bottom dump equipment. This rock was placed with off road end dump trucks and then spread with a small dozer and backhoe. The



View of Stabilized Impoundment Slope

backhoe was used primarily to restore the rock gradation where it had become segregated during dozing.

MATERIALS

Various cover systems were used at the site and required the selection of specific materials to best serve the erosion protection application. Soils and rock materials were obtained from local borrow areas and a near-by quarry. Plant materials were selected from local species and species that provide excellent stabilization characteristics.

SOILS

An inventory and analysis of the locally available borrow soils were conducted in which soil bore holes and test pits were completed to classify the soil materials. Grain size, permeability testing and volumetric analysis were done to understand the relative quantities of each type of soil that was tested. Locations of the various soils were mapped to complete haul designs and equipment optimization. Clayey sand and lean clay soils were used for radon cap and infiltration barrier. Alluvial soils generally of silty sand and clayey sand and silt classifications were used for soil covers and plant growth media. Very low organic mater levels existed in these soils. The soils did require fertilization to promote vegetation growth.

PLANT MATERIALS

A vegetated cover may be placed on the top-slopes of waste piles as an alternative to rock cover. Vegetated covers are generally not acceptable for side-slopes because the vegetation may not be able to resist erosion from high flow velocities.

The key to vegetated cover design is to use the proper combination of plants and soil to assure that some plants survive (even if dormant) during the dry periods so that adequate transpirational capacity will be available after precipitation events to prevent moisture from infiltrating into the contaminated materials.

The vegetation species used at Bluewater were a combination of grasses and forbs. The majority of the species are native and are drought tolerant and adapted to the semiarid southwest conditions. The introduced species are also adapted to dry conditions and provide excellent ground cover. The plant community will provide both ground cover and canopy cover protection of the soil through out the seasons of the year. Seeding rates and procedures were developed from USDA technical guides for critical area stabilization. The cover was prepared as a seed bed, fertilized and mulched.

ROCK

While history has demonstrated that rock has lasting value, not all types of stone weather the same over time. In assessing the long term durability of erosion materials, the NRC has relied on durability tests performed in the laboratory. Laboratory analysis included Specific Gravity, Absorption, Sulfate Soundness, LA Abrasion and Tensile Strength. A scoring system is used to determine the quality of the stone, if it is adequate or if over sizing is required. The Bluewater area had two types of rock available for use as erosion material. Existing quarries in the area produced a quality limestone or the Malpais Formation which was closer, potentially could be quarried for a high quality igneous rock.

The cost to open a pit and mine the Malpais was higher than obtaining locally produced limestone, however, the igneous rock scored higher, alleviating the need for over sizing. Transportation costs were also less because the malpais pit site was adjacent to the Bluewater project. Overall the igneous source was found to provide the best value to the project and was used. The pit produced over 500,000 cubic yards of erosion protection material for the Bluewater project.

QUALITY CONTROL

Quality control testing for erosion protection rock was completed with a quality assurance program that monitored rock physical properties, gradation and placement. Testing for gradation and strength began at the rock quarry as soon as the product was produced. Testing was completed by the quarry contractor. All testing was reviewed and documented by the construction management team. Products not meeting the specifications were returned to the raw material stockpile for reprocessing. It was found that gradations having a wide band of rock sizes were the most difficult to produce and to place. Calculations for alternate erosion protection gradations were made and a request for a gradation adjustment was submitted to the NRC. NRC's quick response and subsequent approval of the recommended revision made both production and placement of the rock more feasible while providing for the same protection on the surface.

Quality assurance during placement consisted of visual inspection during placement followed up by depth of cover testing and insitu gradation analysis. Depth of cover testing was completed on a grid pattern and field measurements photographed to show compliance with specifications. Tracking

sheets and mapping were maintained which logged all testing. Non-complying areas were reworked and retested as described above.

EFFECTIVENESS

The effectiveness of the erosion protection covers has been successful to date. The covers have been in place for 5 to 7 years and no head-cutting, gully or rill erosion has been experienced on the rock corners. Minor flow concentration has been observed where water is flowing around the base of large plants. However these minor water paths are healing with deposition of plant organics and windblown soil accumulation.

It is considered at this point in the erosion protection period that the designs are effective. The test of 995 years is yet to come.

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